ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Master's project in Life Sciences and Technology

Priming With Two Primes

The Interaction of Prime and Target Features

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Abstract

In response priming, the reaction times to classify an object can be affected by previous exposure to a similar object. Most priming experiments focus on how primes prime a target. In the following set of experiments, we investigate how the interaction between two primes prime a target. Specifically, we address if the offsets of the two prime verniers integrate before they prime, and which prime, if any, dominates the integration (and therefore, the priming). We show that the offsets of the primes fuse before they prime. However, other features of the primes (such as color or temporal location) changes how the primes integrate with each other and hence, priming. We see that when the two primes do not equally integrate, the second prime dominates over the first prime.

Aknowledgements

Many thanks to my advisor, Michael Herzog, for being a strong mentor while allowing me to grow as a researcher. In addition, thank you to everyone in the LPSY laboratory for their support, especially Johannes Rüter for his interesting and very helpful discussions and Aaron Clark for making matlab seem so simple.

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1 Introduction

As humans, one of the most basic things we take for granted is our sight. We see the world around us in amazing detail and with amazing accuracy. We take for granted that our brain is able to separate the white of the keyboard from the white of the desk and that when I reach out to touch my soft, knit scarf that the texture I feel will be the same that I have seen. But how are we able to recreate the world around us with such accuracy? How does my brain know that the 2nd and 1,878th photons that are hitting my retina come from my keyboard and the 164th and 823rd photons come from my desk? What the visual system is able to do is truly an incredible accomplishment.

Because our visual systems are able to perform such a difficult task, the visual system has attracted much research into investigating how it performs such difficult tasks. One of the basic questions researchers seek to answer is how we are able to see objects. If both my keyboard and my desk are white, then how am I able to tell that the keyboard is separate object from the desk?

It has been discovered that different centers in the brain process different features of objects. For example, the cells in the early visual system respond to color or orientation. In this way, when a person sees a red circle, parts of the brain detect the color red and other parts detect the shape circle. This information is later integrated to form the perception of a red circle (Figure 1 gives a schematic). If the features of an object are detected in separate parts of the brain, then, how is the brain able to recombine the correct information to reform the object? This question is called the binding problem. The binding problem is particularly challenging when two objects are presented. How can the brain keep track of the fact that my water bottle is red, and my pen is blue and not the other way around? Research on the binding problem, thus, seeks to discover how the brain is able to correctly integrate or bind the features of an object.

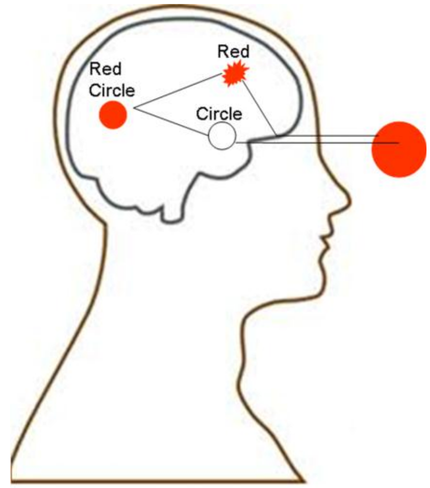

Figure 1. Feature Binding. The brain detects features of an object separately and then binds them together.

Although this issue had been contemplated by many, the binding problem was first directly introduced by von der Malsburg in 1981. Since then, it has been a popular topic of research (von der Malsburg, 1999; Roskies, 1999; Treismann & Gelade, 1980; Treismann & H. Schmidt, 1982; Wheeler & Treismann, 2002). Most experiments on this topic seek to tell, for instance, what role attention plays or at what time they bind. Often times, this research focuses on illusory conjunctions, in other words, when the visual system incorrectly binds the feature from two separate objects. For instance, after viewing a red circle and a blue square, a person may perceive a blue circle and a red square. By studying how these incorrect conjunctions are formed, we can tell how the brain is integrating the features of two objects (for instance, over space or time).

Research performed on feature binding focuses on binding features across domains. For instance, how do we correctly bind an object’s shape and its color? A slightly newer field of research looks at feature integration within a single domain. For example, in feature fusion, the features of two separate objects are integrated, creating the perception of a single, combined feature. For instance, if a red circle is presented immediately before a green circle, the observer perceives one yellow circle (Figure 2) (Efron, 1973). Interestingly, the perceived yellow circle will have a slight green tint.

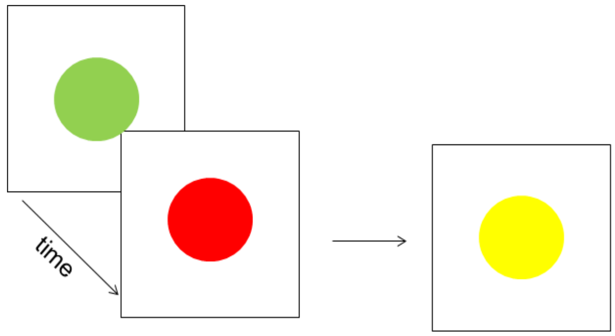

Figure 2. An example of feature fusion. When a green circle is presented immediately before a red circle, the viewer will perceive a single yellow circle with a slight reddish tint.

Feature fusion has recently been studied using verniers, which are two lines which are offset from one another (see Figure 4) (Herzog et al., 2003; Scharnowski et al., 2007; Scharnowski et al., 2009). In these experiments, subjects are shown two verniers with opposite offsets which fuse together to create a single percept. Subjects are asked to report in which direction is the offset of the perceived vernier. Interestingly, the second vernier dominates the percept. This is contrary to current models of decision making (i.e. Smith & Ratcliff, 2004), which predict that because the first vernier enters the decision stage first it should dominate the percept because it has more time to affect the decision. As explained by (Scharnowski et al., 2007), this is also against Bloch's law because in Bloch's law it does not matter whether an object has a duration of 20 ms and is 30 cd/m^2 or a duration of 10 ms and is 60 cd/m^2.

Another basic assumption we take for granted is that we are in complete control over our actions. However, something as simple as seeing an object can actually affect the actions that come after. For instance, we are asked to report the direction a large arrow is pointing but are presented with a small arrow pointing to the right before the large arrow. Our response times to the large arrow will either be slowed down or speeded up depending on which direction the small arrow is pointing in. If the small arrow is pointing in the same direction as the large arrow, the congruent case, then, the reaction times will be sped up. If the small arrow is pointing in the opposite direction as the large arrow, the incongruent case, then, the reaction times will be slowed down. This effect is called the priming effect (see Figure 3 for a schematic). Interestingly, objects that are perceptually invisible can still affect the brain and can still cause the priming effect (i.e. Cheesman & Merikle, 1986; Jaskowski et al., 2002)

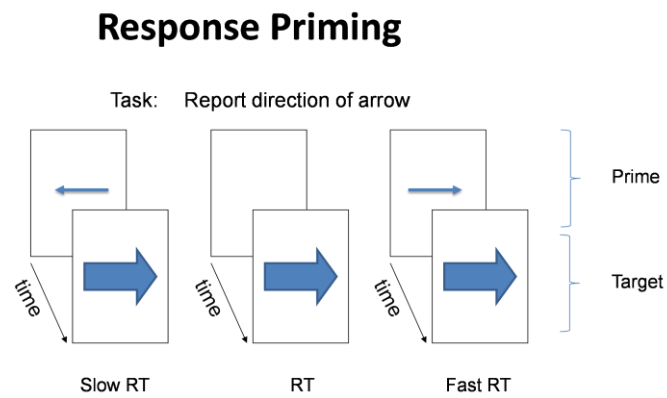

Figure 3. Response priming. Visual stimuli can affect the speed of motor responses.

In priming experiments, it is expected that the first vernier should dominate the priming response when two primes are presented. For time durations of tens to a few hundred milliseconds, the strength of priming increases as the time between the prime and the target (the ISI) increases. This is because the prime has more time to cause an effect in the brain. Because the priming effect increases with the amount of time the prime has in the brain, it is expected that the first prime should dominate the priming response.

Most priming experiments focus on the interaction between one prime and the target. In the following set of experiments, we investigate how the interaction between two primes affects priming the target. Specifically, the main aim of the following experiments is to test if the second prime will dominate the priming response as has been shown in decision making experiments.

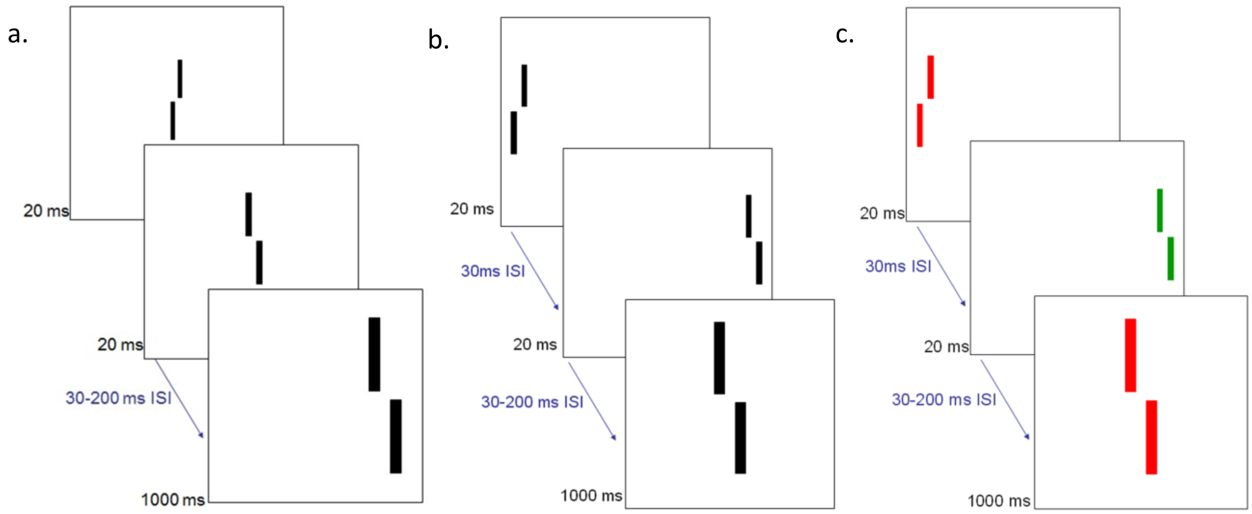

Figure 4. The location of primes and targets in the three experiments. a. In experiment 1, consecutive vernier primes were presented in the center of the screen followed by the target presented on the right of the screen. b. In experiments 2 and 3, the target was presented in the center of the screen and the primes were presented to the sides of the screen. In these experiments, primes which were presented sequentially were separated by 30 ms. In all experiments, the primes and the target were separated by an ISI of 30ms – 200 ms.

The following work has been divided into three experiments. In each experiment, either one or two primes are presented before an inter stimulus interval (ISI) followed by a target vernier. The subject is asked to report the offset direction of the bottom line of the target vernier (Figure 4).

In the main experiment we look at feature fusion. We use two, fused verniers to prime a target vernier (see Figure 4a for an example of the stimuli). We know that the offsets of two verniers fuse to create a single percept (Herzog et al., 2003), but we do not know how this will affect response priming. How will the two verniers prime the target vernier? Current models of decision making and priming suggest that the first prime should dominate the priming response. However, we have seen in other feature fusion experiments that the second vernier dominates over the first. If the offsets of the verniers are balanced so that the fused percept has no offset, will this balance also show in the priming effect (i.e. does fusion occur before priming), or will we see the dominance of one prime over the other? If one prime dominates over the other prime, we wish to know which prime is dominating, and if or how the two primes are interacting.

For all experiments, there are three major possibilities for priming: either the first or the second prime exclusively primes the target, the primes integrate before they prime the target, or there is what we call competitive priming between the two verniers (the first or the second prime is chosen randomly in each trial to prime the target). These different outcomes can be seen for when two primes are presented at different times in Figure 5. By looking at the reaction times, we can tell that either there is fusion before priming the target, or the primes are chosen randomly to prime the target.

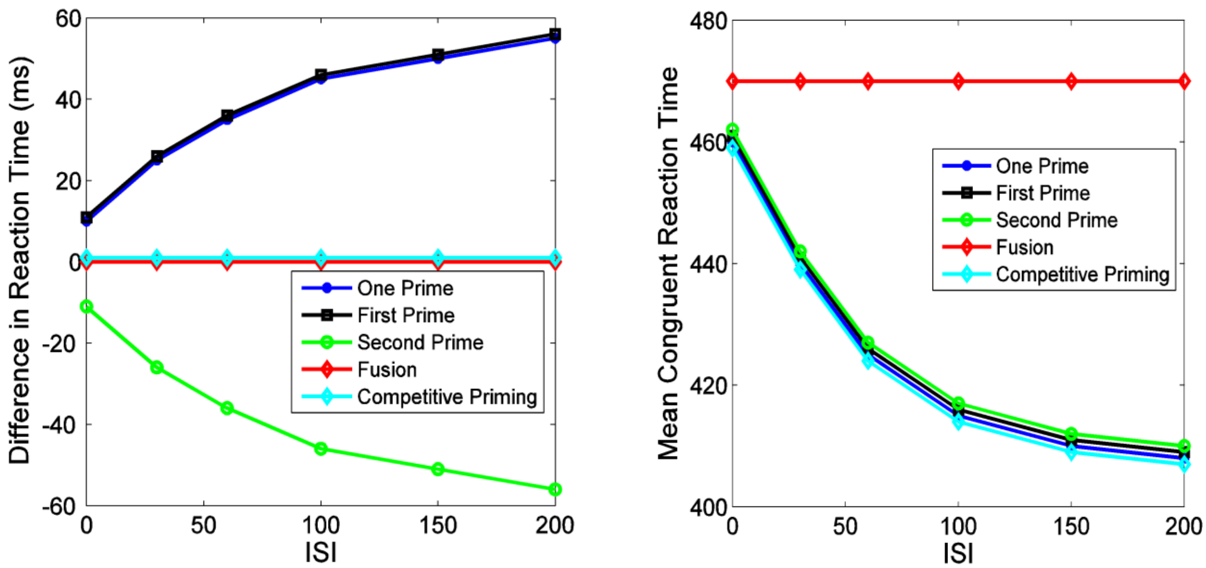

Figure 5. Mock data for the possible outcomes of the experiment. These results are for the condition when two primes are presented at different times. (a) Incongruent – Congruent reaction times. Positive results show the first prime dominates priming and negative results shows the second prime dominates. (b) Mean congruent reaction times. Reaction times for fused primes do not decrease with ISI because priming is not occurring.

2 General Materials and Methods

2.1 Apparatus

In experiments 1 and 2, the stimuli appeared on Tektronix 608 scope using the P11 phosphor. The scope was controlled by a PC using a fast 16-bit DA converter and had a refresh rate of 200 Hz. Verniers were composed of dots drawn with a dot pitch of 200 μm and with a dot rate of 1 MHz. The luminance of the stimuli was set to 80 cd/m^2, and measured with a Minolta LS-100 luminance meter.

In experiment 3, stimuli appeared on a PHILIPS 201B4 CRT monitor. The resolution of the screen was 1280 by 1024 pixels, with a refresh rate of 75 Hz. Gamma corrections were applied to each color channel. The color luminance was measured using a GretagMacBeth 'EyeOne Display 2' colorimeter.

2.2 Observers

Each experiment used five naive subjects and the author of this paper. In experiment 3, different sets of subjects were used for the priming and visibility of prime experiments. Subjects were between 18 and 35 years of age. All subjects, excluding the author, were paid 20 CHF per hour for participating in the experiments, and were informed that they could choose to leave the experiment at any time. All subjects had visual acuities above 1.0 according to the Freiburg visual acuity test.

2.3 Stimuli

In all experiments, subjects viewed the stimuli from 2 meters away. Examples of stimuli used in this experiment can be seen in Figure 4. Stimuli consisted of either one or two prime verniers followed by a blank screen ISI, and then a target vernier. Prime verniers were 600 arcsec in length (with a 60 arcsec gap) and had an offset of 40 arcsec unless specified otherwise. The target vernier was 1200 arcsec in length (with a 60 arcsec gap) and had an offset of 150 arcsec, except when a zero-offset is specified. Five different ISIs were used: 30, 60, 100, 150 and 200 ms. In Experiments 2 and 3, an additional ISI of 30 ms was placed between the two prime verniers when primes appeared at different times. Primes were presented for 20 ms each. The target was presented for 1000 ms.

In experiment 1, the primes were presented in the center of the screen and the target was presented 1200 arcsec to the right of the primes. In experiments 2 and 3, the target was presented in the center of the screen, and the primes were presented 1200 arcsec either to the right, the left, or both the right and left of the target. Figure 4 shows the location of presentation for the primes and target in the experiments.

In conditions with two primes, the second prime had the opposite offset direction as the first prime except for in the same direction condition in experiments 2 and 3, where the two primes had the same offset direction. Because the offset of the primes were independent of the offset of the target vernier, there were two different cases; in the congruent case, the first prime was offset in the same direction as the target and in the incongruent case the first prime was offset in the opposite direction as the target. Because the second prime had the opposite offset as the first prime (except for in the same direction condition), cases where the first prime was incongruent can also be considered cases when the second prime was congruent with the target.

The target vernier was larger and had a larger offset than the primes in order to make the offset direction obvious and create low error rates, thus avoiding the speed-accuracy tradeoff. The primes and target were presented in different locations so that the primes' signals were not masked by the target.

2.4 Experimental Design

Two types of experiments were performed: experiments which investigated the priming effect and experiments which determined the visibility of the offsets of the primes. For priming experiments performed in experiments 1 and 2, the subjects completed 12 blocks of 100 trials each for each condition. Each block consisted solely of trials from one condition and with each ISI presented randomly within the block. In experiments where primes were presented on separate sides of the screen, two separate programs were created. One program had the first prime presented on the right for the 30 ms ISI (and alternating sides of presentation for the other ISIs), and the second program had the opposite sides of presentation. In this way, the side that the first prime was presented on was randomly presented during a block. The different conditions were completed in a random order for the first six blocks then in the reverse order to prevent learning.

For the priming experiment in experiment 3, all conditions were presented randomly rather than in a block-wise fashion. Subjects completed two sessions of five blocks each.

Within each block, there were 160 trials composed of each of the five conditions. Blocks were separated by an optional pause.

In the prime visibility experiment in experiment 2, subjects were asked to report the offset direction of a prime vernier which was followed by a zero-offset target vernier. The offset of the prime was always 40 arcsec. In experiment three, the offset of the prime was varied using an adaptive PEST procedure (Taylor & Creelman, 1967).

In priming experiments, the subject was asked to report as quickly and as accurately as possible in which direction the target vernier was offset by pressing either a left (for a left offset) or a right (for a right offset) hand button.

In experiments investigating the visibility of the prime offset, subjects were asked to report the offset direction of the only prime or one of the two primes. Subjects were told that accuracy was more important than speed.

2.5 Data Analysis

In all experiments, unless otherwise stated, incorrect responses and reaction times outside of three standard deviations were ignored in data analysis. Results are displayed as the mean reaction times for each ISI or as the difference in reaction times between incongruent (prime offset direction is the opposite of the target) and congruent (prime offset direction is the same as the target) trials for each ISI.

If two primes were presented, conditions where the first prime was incongruent with the target were also conditions where the second prime was congruent with the target. Because of this, positive differences correspond to the reference prime dominating the response and negative differences correspond to the non-reference prime dominating the response. When two primes were presented at different times, the reference prime is the first prime. When two primes were presented at the same time, the reference prime is the right prime in experiment 2 and the red prime in experiment 3.

To compute statistical significance, a two-way, repeated-measure ANOVA was performed between all conditions within an experiment to find a main effect and an interaction between the condition and the ISI. Post-hoc analysis was performed between individual conditions to determine which conditions were significantly different.

To look at the strength of the priming effect, the slopes of the conditions were calculated for the differences in reaction time. To determine if priming was occurring, a one sample, two tailed t-test comparing the slope with zero was performed. If the slope is significantly different from zero then it suggests that the target was being primed. Flat slopes suggest that the target was either not being primed, due to offset integration before priming, or competitive priming.

3 Experiments

3.1 Feature Fusion.

In the first experiment, we looked at feature fusion. We presented two consecutive verniers with opposite offsets as primes. The verniers were presented in the same spatial location but at different times. The primes, which were presented for 20 ms each, were presented immediately after one another. With this experiment, we sought to address whether the verniers' offsets integrate in the brain before they prime the target or whether the first of the second prime offset primes the target.

3.1.1 Methods

In order to perform the priming experiments, we first had to adjust the offsets of the primes so that the two primes fused on average to a zero offset vernier. Subjects were shown two verniers (the second having the opposite offset of the first) presented immediately after one another and were asked to report the offset direction of the perceived vernier. The stimulus used was the same as the two-prime priming sequence used in the priming experiment. Subjects were not told there were two verniers. After 80 trials, the percent correct in accordance to the first vernier was determined and the offset of the second vernier was adjusted accordingly (the offset was increased if the percent correct was above 50 percent, and vice versa). The offset was adjusted until the subject answered 5 percent above or below 50 percent correct. The offset of the primes was adjusted for each subject before each session.

After adjusting the offset of the second prime, subjects began the priming experiment. There were three different conditions in this experiment. One control, called the no prime condition, had the target only and no primes (Figure 6a). This condition gave information about the baseline reactions without any priming. The second baseline condition, called the one prime control, had only one prime (Figure 6b). This control was used to determine if the subject was experiencing a priming effect and was used as a reference for mean reaction times. The third condition had two primes, and was used to investigate feature fusion and priming (Figure 6c).

Because the target was presented to the right of the primes, it is possible that some people would naturally fixate only on the location where the target was presented and not on the location where the primes were presented. If this happened, then the prime verniers would not be attended and would not prime. Hence, the subjects were given specific instructions to fixate on the center of the screen until the target appeared in order to insure that the primes were not ignored. The subjects were told that the primary task of the experiment was to report

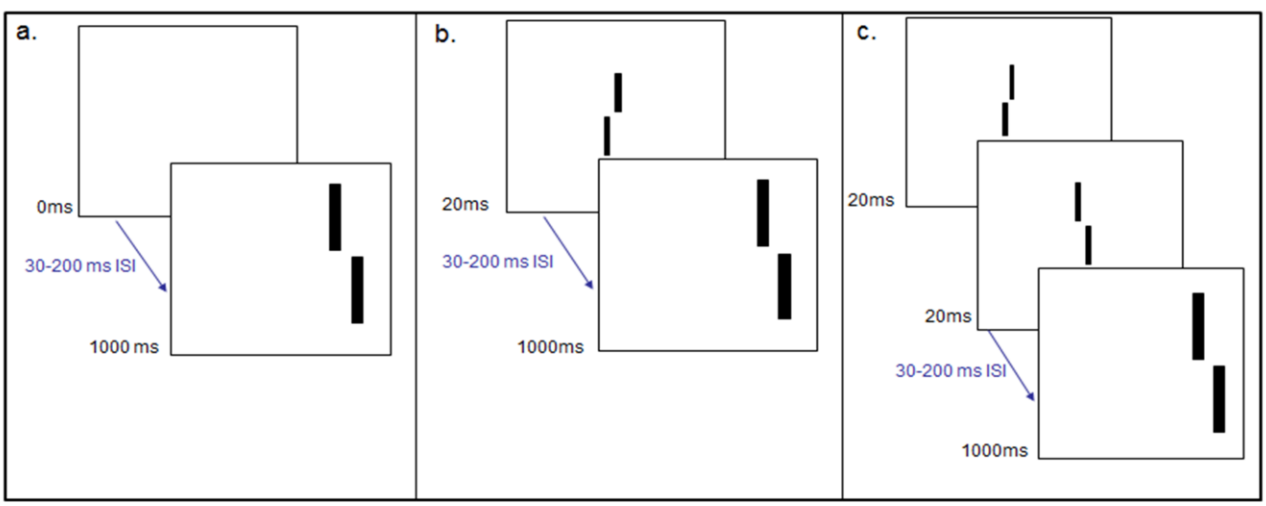

Figure 6. The three different conditions used in experiment 1. a. The no prime condition was used to obtain a baseline reaction time. b. The one prime condition was used as a control for priming. c. The two primes condition was used to investigate feature fusion.

the offset direction of the target vernier, but that the secondary task was to fixate on the fixation point at the beginning of each trial.

3.1.2 Results

The goal of this experiment was to see which prime dominates the priming response and if feature fusion occurs before or after response priming.

Figure 7 shows the difference in reaction times between the one prime and two primes conditions. As expected, the difference between incongruent and congruent reaction times for the one prime condition increases as the ISI increases. The slope of the one prime condition is 0.20. This value is significantly significant from zero ($p \leq 0.001$). For the two primes condition, the difference in reaction times is zero except for when the ISI is 30 ms (slope of -0.049). There is a main effect between the one prime and two primes condition ($p \leq 0.01$) and a significant interaction between the condition and ISI ($p \leq 0.00001$).

Figure 8a shows the mean incongruent reaction times. There is a main effect between the different conditions ($p = 0.023$) and a significant interaction between the condition and the ISI ($p = 0.032$). Post-hoc analysis shows that the two primes condition is significantly different from the one prime condition ($p \leq 0.001$).

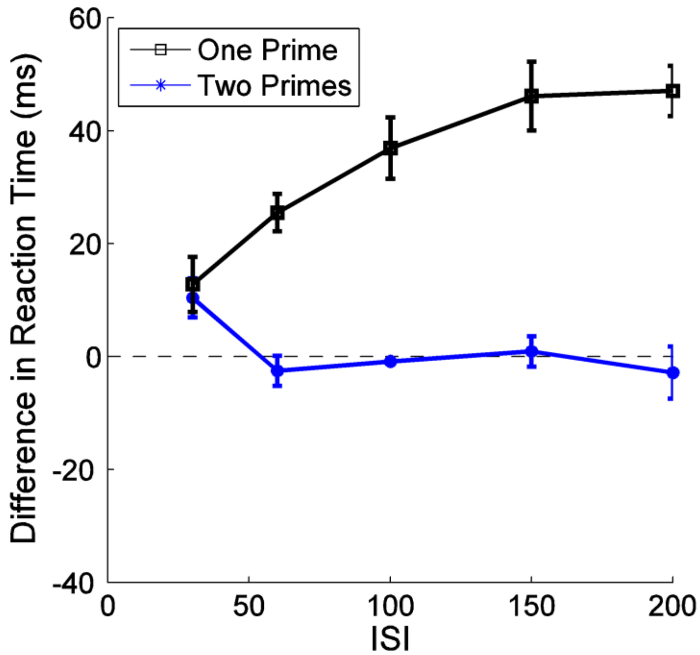

Figure 7. Difference between incongruent and congruent reaction times in experiment 1. When there are two primes, positive numbers indicate the first prime is dominating the priming response, while negative numbers indicate the second prime is dominating the response.

The mean congruent reaction times are shown in Figure 8b. There is a main effect between the different conditions ($p= 0.005$), and a significant interaction between the condition and the ISI ($p\leq 0.001$). Post-hoc analysis shows that there is a main effect between the one prime and the two primes conditions ($p= 0.011$) and a significant interaction between the two conditions and ISI ($p\leq 0.0001$).

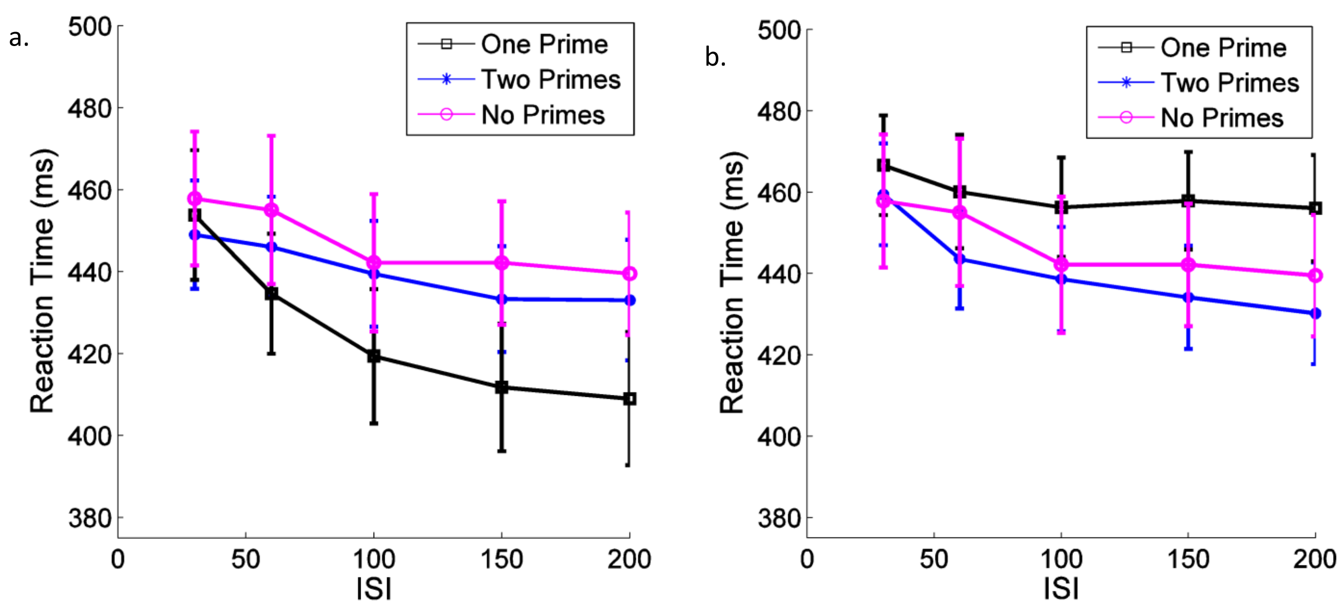

Figure 8. Mean congruent (a) and incongruent (b) reaction times for experiment one. The mean reaction time for the no prime condition is plotted on both graphs for a comparison.

3.1.3 Discussion

To test which prime dominates the priming response and whether features fuse before response priming, we look at both the difference in reaction times between the incongruent and congruent conditions (which is a measure of the priming effect) and at the mean reaction times.

In Figure 7, the there is a positive slope for the difference in reaction times for the one prime condition, and this slope is significantly different from zero. This shows that the prime primes. In this figure, we also see the slope of the difference in reaction times for the two primes condition was around zero. In addition, the difference in reaction times values for all ISIs were around zero, except for 30 ms ISI. To explain this result, the zero-valued reaction times will first be addressed.

There are two probable explanations for why there was no difference in reaction times for the two primes condition. The first explanation is that the offset information from both of the primes integrates before the information primes the response to the target. In this case, the two offsets combined to create a zero-offset prime, which has no directional information for priming. Therefore, the target is effectively not being primed. Because there is no priming occurring, the mean congruent reaction times should be different from the one prime condition, because there is no offset to speed up the reaction time. This is, indeed, most likely the case.

The second explanation is that the offset information does not integrate before priming; rather, there is, as we call it, competitive priming between the two offsets. There are two different models which can explain the competitive priming. The first model is that the first offset begins to prime the response, but before the offset reaches the threshold to prime the response, the information from the second prime enters the system and cancels out the information from the first offset, bringing the priming response back to zero. In this case, as in the integration-first case, the information from the primes is not used to prime the responses to the target. If this is the case, the reaction times for the two primes condition should be the same as in the one prime condition. This is most likely not the case.

The second model is an independent race model in which the information from the primes is stored separately. Both offsets prime the target, but because the primes are balanced to give a zero-offset percept, each prime has a 50% chance of being chosen to prime the target. Therefore, across trials neither prime dominates the response on average. This model gives the fastest response times because the offset information is being used to prime the response to the target. In this case, for the mean congruent reaction times, the two primes condition would be faster than the no prime condition, and the same as the one prime condition. This is not the case.

Because the mean congruent and incongruent reaction times for the two primes condition is significantly different from the one prime condition, we can conclude that the two primes are not competing as in an independent race model. We are therefore left with two possibilities: the primes fuse before they prime the target or both primes prime the target but cancel each other out.

A further suggestion that the two primes were fusing before priming is that both the mean congruent and mean incongruent reaction times are not significantly varying with increasing ISI for the two primes condition. The strength of priming increases as ISI increases, so the mean congruent and incongruent reaction times decrease or increase, respectively, with increasing ISI. Because there is not a large change, it suggests that fusion occurs before priming.

Another interesting effect was that for an ISI of 30 ms, the difference in reaction times is around 10 ms. This nonzero value is comparable to the no antivernier, control condition. One possible explanation for the higher than expected difference in reaction times is that there is a complex interaction between forward masking from the first prime and backward masking from the target, which causes the second prime to be masked. When the second prime is masked, the first prime cannot fuse with the second prime and is available to prime the target. Another explanation is that the target comes before the second prime has time to have its full effect. This is unlikely because we can see from the one prime condition that an ISI of 30 ms is enough for a prime to have an effect. This effect could also simply be explained by noise in the data, due to the fact that it is a small effect.

From this experiment we see that the features of two objects are either fused together before response priming or they are both used to prime the response but separately in separate trials.

3.2 Experiment 2: Feature integration

In this experiment, we looked at feature integration across space and time. In order to determine the effects of the temporal and spatial location on feature integration and response priming, the stimuli from the first experiment were adjusted to prevent feature fusion. The question we sought to answer was: How does the spatial and temporal location of the primes effects how the primes integrate and prime the target? In addition, do the features integrate before they prime or is there competitive priming between the primes?

3.2.1 Methods

The goal of this experiment was to investigate whether the features of two objects integrate before they are used to prime a target and to determine if the first or second prime dominates the priming response.

The prime verniers were presented on different sides of the screen and the target was presented in the center. The primes were presented on different locations of the screen in order to prevent feature fusion. In this way, we focused on feature integration across time. The condition which had two primes presented sequentially had an ISI of 30 ms inserted between the primes to insure that one of the primes was not being ignored.

The first part of this experiment looks at the response priming caused by the different conditions. In the second part of this experiment, we looked at the visibility of the prime offset.

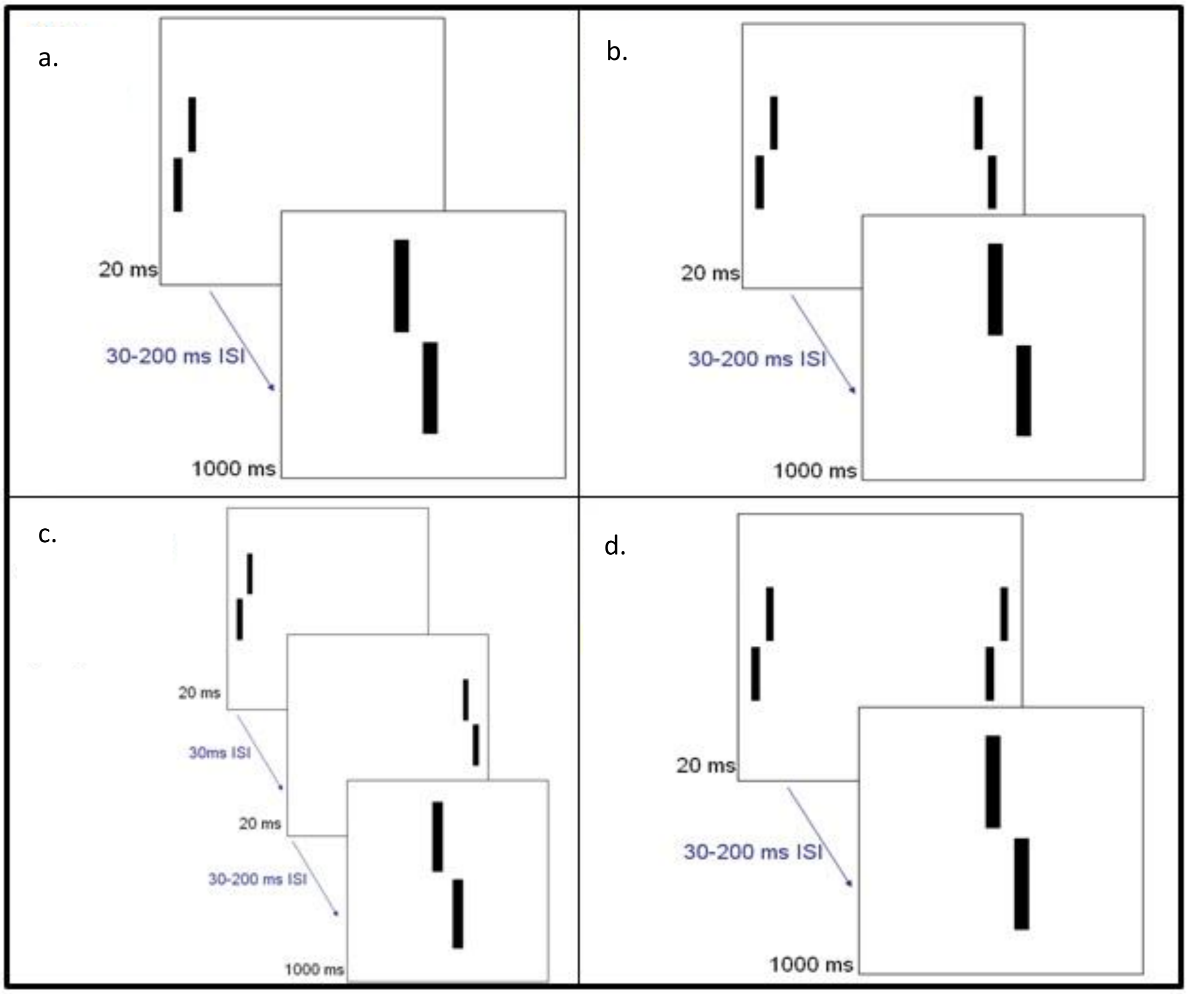

Figure 9. The four different conditions used in experiment 2. a. The one prime condition was used as a control. b. The same time condition investigated if features integrated before priming. c. The different times condition investigated which prime would dominate priming. d. The same direction condition further investigated when the primes integrated.

Response Priming

To test our aims, four experimental conditions were used, as seen in Figure 9. The one prime condition was used as a control to prove that the stimuli show a priming effect and to give a reference reaction time for the other conditions. The other conditions were used to see how the two primes interact, and to test if the offsets integrate before or after they prime. The same time condition, which had two primes at the same time with opposite offsets, tested if the offsets cancel each other out, creating a smaller priming effect. The same direction condition, with two primes presented at the same time but with the same offset direction, tested if the offsets add to each other to create a stronger priming effect. The different times condition, which had opposite offset primes presented 30 ms apart, was used to test if the offsets integrate and what effect temporal location has on the integration.

Visibility of the Primes

In order to determine if subjects could consciously perceive the offset direction of the primes, subjects were asked to report the direction of offset of the prime. For this, we used the one prime condition with a zero-offset target vernier. The target had no offset so that it did not influence the response of the subject. For this experiment, we only used an ISI of 150 ms, as multiple ISIs were not needed to determine the visibility of the prime.

3.2.2 Results

Response priming

This experiment was performed to investigate whether offsets integrate before they prime the target and if the first or second prime dominates the priming response. In addition, if features integrate before they are used for priming, we sought to investigate how temporal location impacts the integration.

Figure 10 shows the difference in reaction times. This graph shows the priming strength of the primes. Positive results show that the first prime (or the right prime, when two primes are presented at the same time) dominates priming, as where negative results show that the second prime dominates priming.

The one prime condition shows that priming can occur with this experimental design. The one prime condition has a slope of 0.129, which is significantly different from zero ($p \leq 0.001$). The one prime condition is significantly different from the different times and the same time conditions ($p = 0.001$ and 0.011, respectively). In addition, ANOVA analysis shows that there is a main effect for the different conditions ($p \leq 0.0001$) and a significant interaction between the conditions and ISI ($p \leq 0.0001$). Post-hoc analysis shows that the same time and the one prime condition have a main effect ($p=0.002$) and an interaction between the condition and ISI ($p \leq 0.001$).

When two primes with opposite offsets are presented at the same time (same time condition), there is no difference in reaction times between the incongruent and congruent cases of the right prime. This is shown in the difference in reaction times graph because the reference prime was the right prime (so positive values would indicate that the subject was attending the right prime more). The same time condition was used not only to test if the subject would favor primes presented on either the right or left side, but was used also to show that there was some interaction occurring between the two primes. This condition had a slope of -0.0015.

To test if features can integrate over space and time, two primes were presented on opposite sides of the screen with a 30 ms ISI in between (the different times condition). The ISI in between the primes allows the subject to attend both primes.

The different times condition has a slope of -0.18, which shows that the second prime dominated the priming effect. The magnitude of the difference in reaction times was less than that of the one prime condition for ISIs up to 100 ms.

The same direction condition, which had two primes with the same offset presented at the same time, was used to investigate if the effect caused by the individual primes can add together to create a stronger effect.

This condition further investigates whether the offset information integrates in the brain. The same direction condition has a slope of 0.0134, which is significantly different from zero (p= 0.0045). The same direction condition was not significantly different from the one prime condition (p= 0.13).

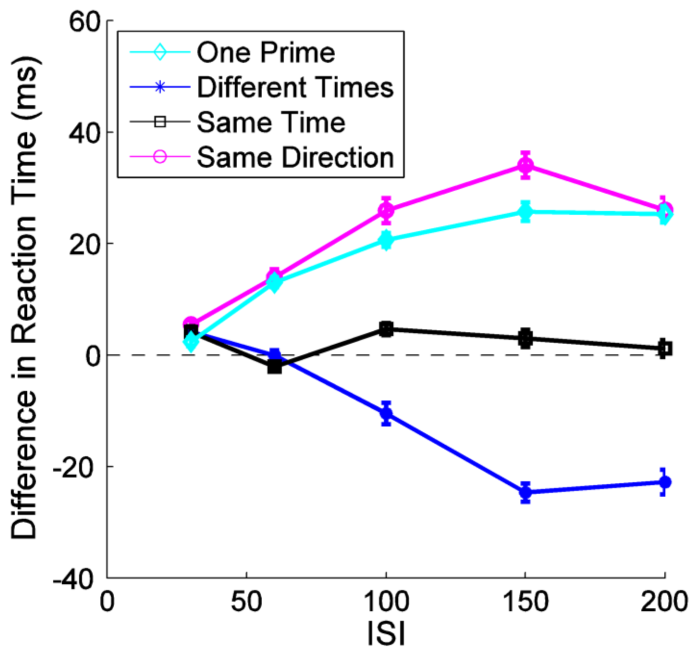

Figure 10. Difference between incongruent and congruent reaction times for experiment 2. Positive numbers indicate the first prime (or right prime when two primes appear together) is dominating the priming response, while negative numbers show the second (or left) prime is dominating the priming response.

Figure 11a shows the mean congruent reaction times. There is an main effect between the different conditions (p= 0.002) and an interaction effect between the condition and ISI (p≤ 0.0001). The same time and the one prime condition are significantly different from one another (p= 0.045).

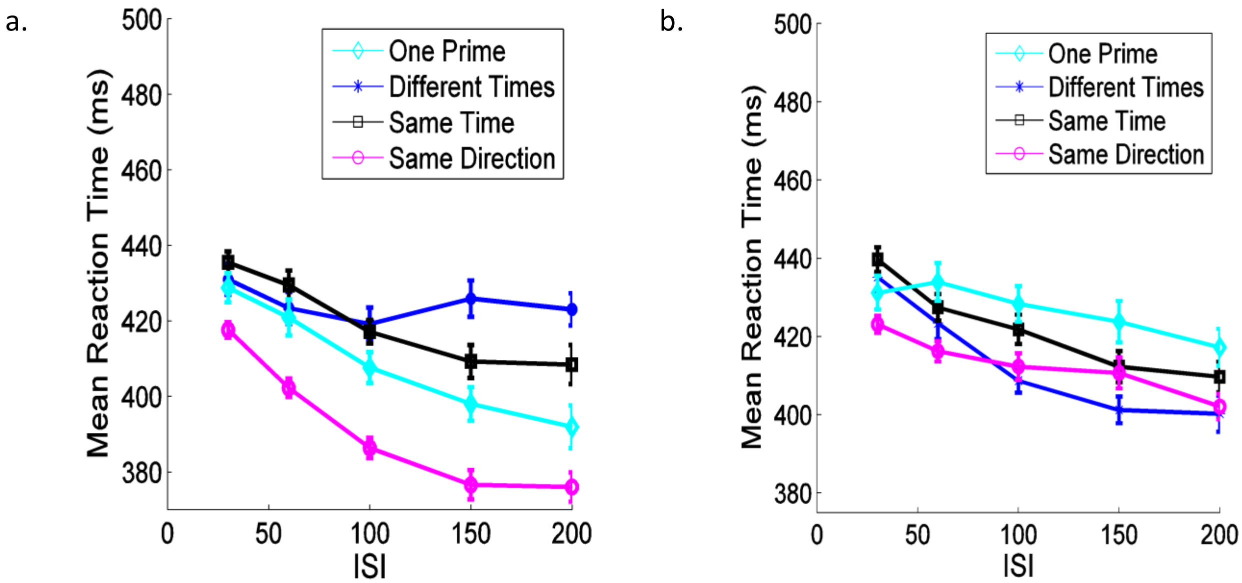

Figure 11. Mean reaction times from Experiment 2. a. Mean reaction times when the first (or reference) prime is congruent with the target. b. Mean reaction times when the first (or reference) prime is incongruent with the target.

Figure 11b shows the mean incongruent reaction times for the different conditions. Although there is no main effect between the different conditions, there is a significant interaction between condition and ISI ($p \leq 0.00001$). The one prime and same time condition showed an interaction effect ($p = 0.001$).

Visibility of the primes

In addition, we also tested the visibility of the offset of the primes. On average, subjects were able to correctly report the direction of offset of the primes in 75.9 percent of the trials. This is above the chance level for guessing, and therefore it can be concluded that subjects were able to consciously perceive the offset direction of the primes in at least in half of the trials.

3.2.3 Discussion

In the first experiment, we were left with the question as to whether the features were fusing before priming, or if there was competitive priming between the two primes. The results from the different times, and to a lesser extent, the same direction conditions show that the offsets of the primes integrate before priming the response to the target.

In Figure 10, we see the difference in reaction times. The one prime condition shows that the primes are able to prime the response to the target because the slope is significantly different from zero.

We then investigated how information from different primes could interact within the brain. When two primes with opposite offsets were presented at the same time, the difference in reaction times disappeared and the slope of the line was close to zero. This could be caused either by the integration of the offsets before the priming effect occurs (and therefore, a disappearance in priming) or by competitive priming by stimuli that are equally likely prime the target.

If there is competitive priming between the two primes, then the presences of both primes should be enough to have the difference in reaction times go to zero. The difference in reaction times having a slope that is significantly different from zero suggests that there is integration between the two primes before they prime. Interestingly, the slope of this line is negative, which shows that the second prime dominates the priming response. Further rejection of competitive priming comes because the mean congruent reaction time of the different times condition is significantly different from the one prime condition. If competitive priming were occurring then the two conditions would have the same mean congruent reaction time because for each trial the different times condition would be fully primed by one or the other prime. The difference between these two conditions suggests that the offsets of the two primes interact before they integrate.

An interesting result is that the difference in reaction times for the different times condition starts out below that of the one prime condition then rises to around the same levels as the one prime condition for long ISIs. This can be explained by the information of the offsets being stored in a leaky buffer before priming the response (Rüter et al., in revision). Because the first prime is being stored for longer than the second prime, more information is lost. If the information decays exponentially, then after a certain amount of time there will be no information from the first prime and the second prime can fully prime the target. To further investigate this the ISIs should be increased beyond 200 ms to see if the priming effect caused by the second prime begins to decay.

The same direction condition helps to further prove that the offsets of the primes are integrating before they prime. In this condition, two primes with the same offset direction are presented at the same time. Competitive priming would lead to the same difference in reaction times as in the one prime condition. If the prime offsets are interacting in the brain, then it is expected that the difference in reaction times would be larger than the one prime condition. Because the slope of the same direction condition is significantly different from zero, it suggests that priming is occurring. In addition, the same direction condition does not have the same difference in reaction times as the same as the one prime condition, which suggests that there is an interaction between the primes.

Although the results from the difference in reaction times hints that the prime offsets are integration before priming, the results from the mean reaction times clearly shows that this is the case. The fact that when two primes are presented with the same offset, the congruent reaction time is significantly different from when two primes are presented with different offsets shows that the prime offsets from the two primes are interacting. The offsets are either adding together to create a faster reaction time (and therefore more priming) or are subtracting from one another to create slower reaction times (or less priming). In addition, the conditions with two primes with opposite offsets are significantly different from the one prime, control condition. This further proves that the offsets are integrating and subtracting from one another.

A further suggestion that the two primes were fusing before priming is that the mean congruent reaction times are not significantly varying with increasing ISI for the different times and same time condition. Because the mean reaction times would decrease with increasing ISI if priming was occurring, it suggests that fusion occurs before priming.

Taken all together, this experiment proves that the offsets of the primes are integrating before they are used to prime the response to the target, but they do not necessarily have to fuse.

3.3 Experiment 3: Colored Primes

In the next set of experiments, color was added to the stimuli in order to differentiate between the two primes so that we could further investigate why the second prime was dominating the priming response in the previous experiments. In the first part of the experiment, we look at the ability of the different conditions to prime and in the second part we look at the visibility of the primes (in order to see if the visibility of the offsets can explain the priming effects seen).

Vernier offset discrimination can be increased or decreased by the presences of objects flanking the vernier. Researched performed by Malania et al. suggests that the reason for the increase or decrease in ability to distinguish the offset of the vernier is due to grouping of the vernier with the objects (2007). If flanking objects are grouped with the vernier, then the discrimination decreases. If flanking objects are grouped separately from the vernier and the vernier stands out from the flanking objects, then the discrimination increases compared to the grouped-together conditions. Sayim et al. showed that changing the color of the vernier and the flankers is one such method of separating the grouping of the flanker and the vernier (2008).

In this experiment, we wished to investigate if we could use color to create differential groupings between the two primes and the target, and if this differential grouping would affect how the offsets of the primes integrated and primed the target.

3.3.1 Methods

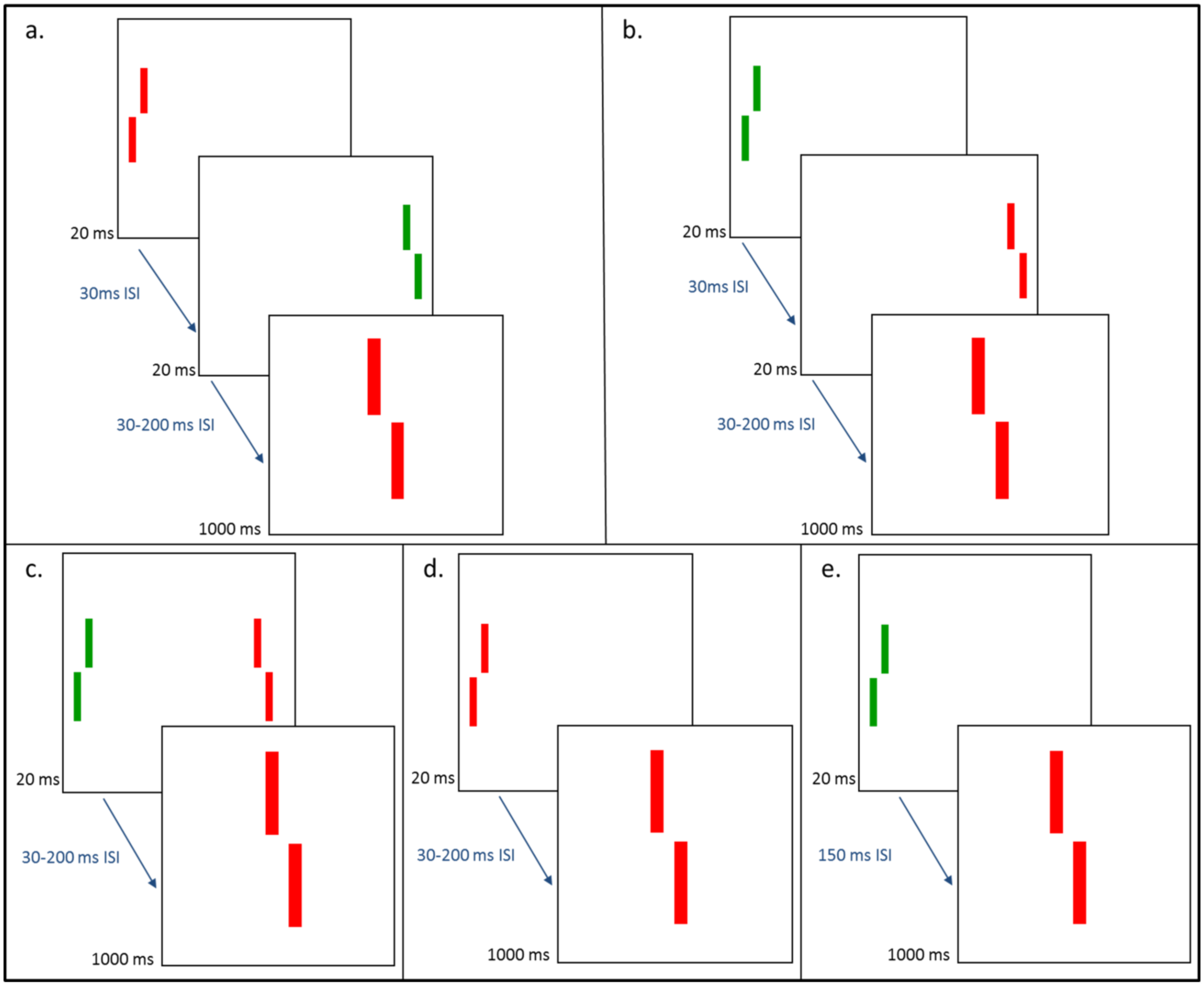

Figure 12. Conditions used in experiment 3. The color of the primes was varied in order to further investigate the role that temporal location has on priming. a. Red then green condition. b. Green the red condition. c. Same time condition. d. Red prime only condition. e. Green prime only condition.

Response priming

This experiment used the stimuli conditions from the previous experiment, but introduced different colors to the primes and target in order to create a difference in grouping between the primes. As in the previous experiment, prime verniers were presented on the sides of the target vernier. The side the first, or only, prime was presented on was randomized between trials. Prime verniers could either be red or green, while the target vernier was always red. The luminance of the colors was adjusted so that the green prime primed the red target as strongly as the red prime primed the red target. Luminance values were 24 cd/m^2 and 39 cd/m for red and green, respectively.

There were five different conditions, as can be seen in Figure 12. Stimuli had either one prime (red or green), two primes presented at the same time with opposite offsets, or one prime presented 30 ms after the a first prime (with both the red and the green primes coming first). The one prime conditions were used to set up a baseline of priming and to balance the priming effect for the two colors. The condition with two primes presented at the same time, the same time condition, was used to investigate whether the subject would use either the red or the green prime to prime the target or if the subject would integrate the offsets of the two primes. The different times conditions, in which two primes were presented sequentially, were used to investigate the effect that the primes had on each other and on the target. This condition tested if the first or second prime dominates the priming response. Our hypothesis was that the offsets of the two primes would interact before priming, but that the second prime would dominate the priming response.

As opposed to other experiments, the different conditions were presented in a fully random design rather than in a block-wise fashion. Subjects completed two sessions of five blocks each. Within each block, there were 160 trials composed of each of the five conditions. Blocks were separated by an optional pause.

Visibility of the Primes

In addition to investigating the role of the temporal order on the priming strength of the primes, we also measured how the components within the stimuli affected the visibility of the offsets of the primes. We questioned whether a prime’s ability to prime the target is determined by the prime’s offset visibility.

We measure how small of an offset the subjects could accurately perceive for each prime in each of the conditions in the priming experiment. The conditions were the same as stated above except the target had no offset (the offset was zero). Subjects were asked to report the offset direction of a specific prime in a given condition. For conditions having two primes, each prime was attended in separate blocks. For instance, in one block the subject was asked to report the offset direction of the green stimuli and in a separate block the subject reported the offset direction of the red prime. The offset value was varied for the attended prime using an adaptive PEST procedure. Subjects were considered to perceive an offset if they were at or above the 75 percent correct.

3.3.2 Results

The goal of this experiment was to investigate further how object features are integrated over space and time and how this integration affects response priming. To achieve a balanced priming effect for red and green primes priming a red target, the luminance of the green prime was increased from 24 cd/m^2 to 39 cd/m^2.

Response priming

Figure 13 shows the difference in reaction times for experiment 3. The red prime only condition has a slope of 0.34 (standard error of 0.095), which is significantly different from zero ($p = 0.0059$). The green prime only condition had a slope of 0.22 (standard error of 0.10), which is significantly different from zero (p= 0.034). The same time condition has a slope of 0.072 (standard error of 0.061), which is not significantly different from zero (p= 0.14). The green then red condition has a slope of -0.25 (standard error of 0.095), which is significantly different from zero (p=0.022). The red the green prime condition has a slope of -0.12 (standard error of 0.10), which is significantly different from zero (p= 0.014).

In addition to comparing the slopes, ANOVA analysis shows that there is a main effect between the different conditions (p= 0.006), and an interaction between the condition and ISI (p= 0.005). Post-hoc analysis shows that the red before green condition is significantly different from the green prime only condition (p=0.016) and there is an interaction effect between condition and ISI (p= 0.001). There is no significant difference between the magnitude of the green before red condition and the red only condition.

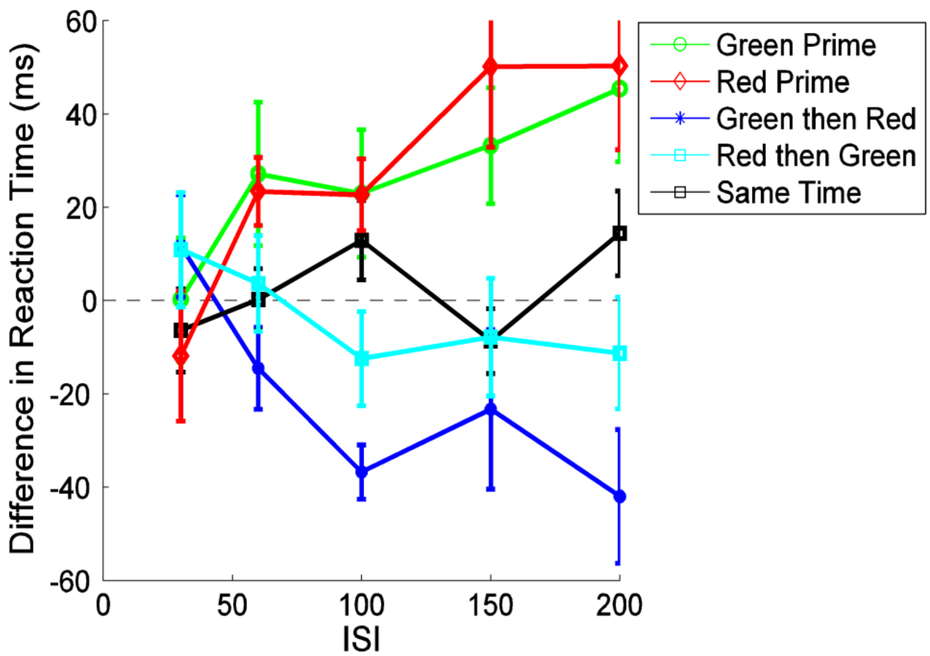

Figure 13. Difference between incongruent and congruent reaction times in experiment 3. Positive numbers indicate the first prime (or right prime when two primes appear together) is dominating the priming response, while negative numbers show the second (or left) prime is dominating the priming response.

When two verniers with opposite offsets were presented at the same time, neither the red nor the green prime dominated the response (the slope of the line is not significantly different from zero). Looking at the condition where a green prime was presented before a red prime, we see that the second, red prime is dominating the priming response. We find no significant difference between the green then red condition and the red prime only condition.

Looking at the mean incongruent reaction times, Figure 14a, we can see if the responses to the target were primed. There is a main effect between conditions ($p= 0.002$) and an interaction effect between condition and ISI ($p= 0.008$). Post-hoc analysis shows that the red before green condition and green only conditions are significantly different ($p= 0.009$). The green before red and the red only condition are not significantly different.

The mean congruent reaction times, Figure 14b, show a main effect between the different conditions ($p= 0.005$) and an interaction effect between the condition and ISI ($p\leq 0.001$). Post-hoc analysis shows that the red before green condition and green only conditions are significantly different ($p= 0.036$), and an interaction effect between the condition and ISI ($p= 0.004$). The green before red and the red only condition are not significantly different.

There are no significant differences between the same time condition and any of the other conditions.

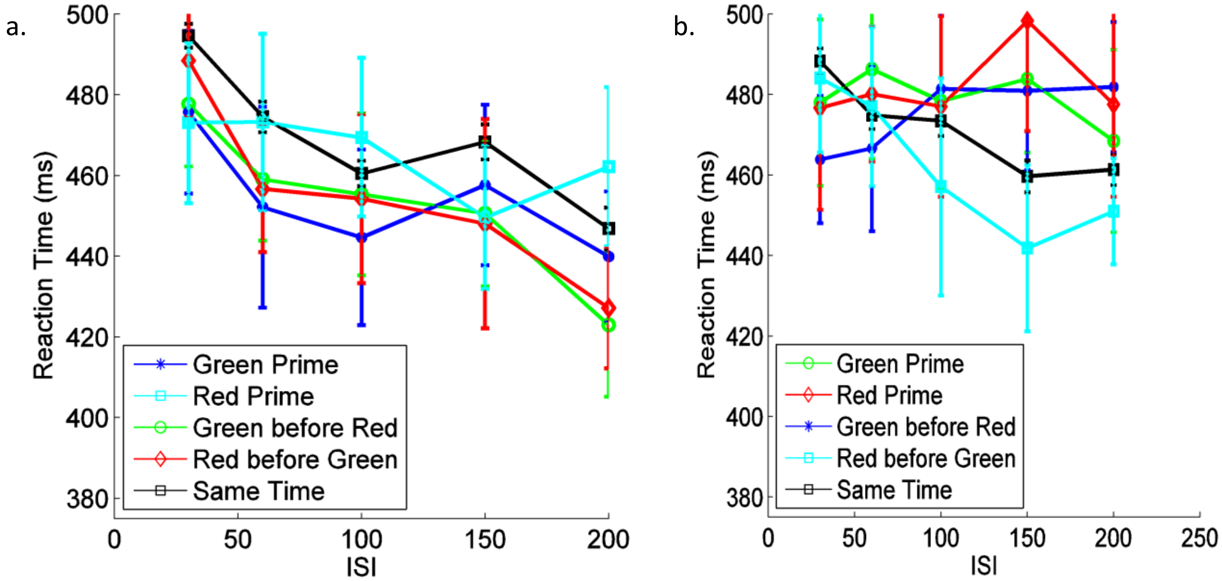

Figure 14. Mean reaction times from experiment 3. Mean reaction times when the reference prime is a. congruent or b. incongruent with the target.

Offset of the Primes

Figure 15 shows the threshold of visibility of the offset of the primes. Although there are no significant differences between the red and green conditions, or between any of the conditions within a color, there is a linear upwards trend (p= 0.016). In addition, subjects had lower thresholds when the primes were presented alone then when primes were followed by a target. Thresholds of visibility were below the offset presented during the priming experiment (40 arcsec).

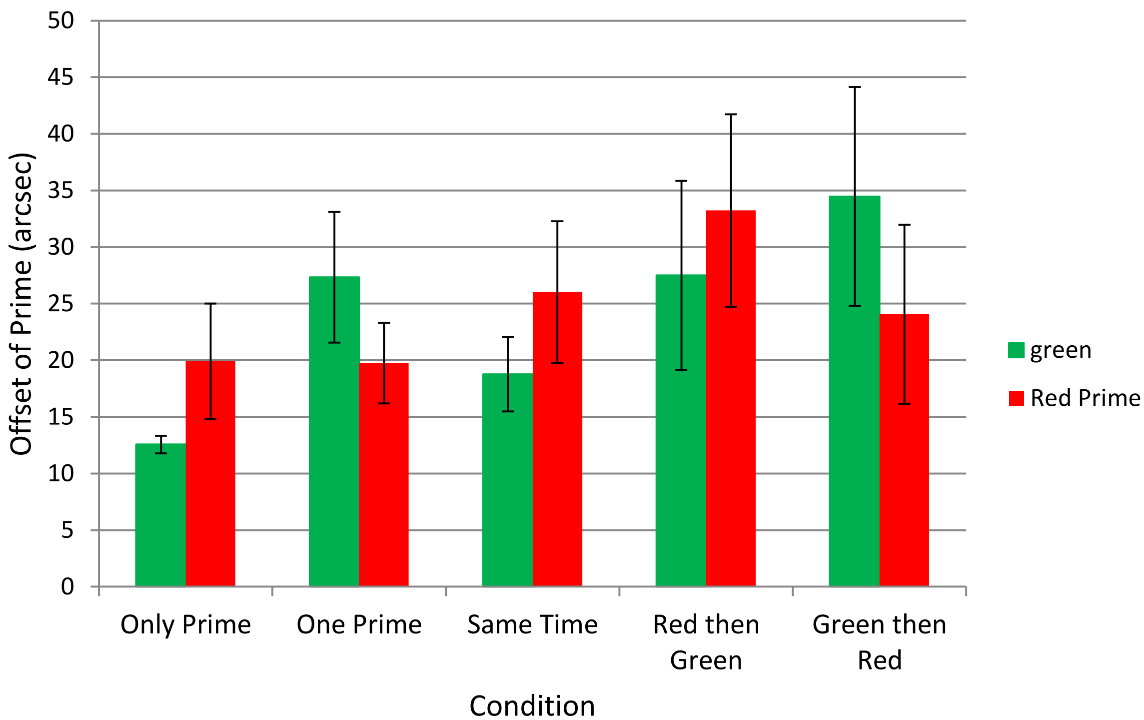

Figure 15. Thresholds of visibility of the offset of the primes. Error bars show standard error.

3.3.3 Discussion

The goal of this experiment was to investigate further why the second prime was dominating the priming response, and to look at the effect that color, and perceptual grouping, has on priming.

Response Priming

The red prime condition shows that the red prime primes the red target. Because the green prime condition is close to the red prime condition, it can be seen that the two colors have been balanced in the priming effect. In addition, because the luminance of the green prime had to be increased by 15 cd/m^2, it can be concluded that the red prime primes a red target better than a green prime primes a red target. One explanation as to why this occurs is that the brain groups the red prime with the red target more strongly than the green prime with the red target due to color similarities. Because the brain groups the target with the red primes more than the green primes, there is more of a similarity to cause priming.

We then tested the effect that temporal location (either before, at the same time as, or after a prime of a different color) has on priming. When two primes were presented at the same time, the slope of the line of best fit for the difference in reaction times was close to zero. For this condition, positive values indicate dominance of the red prime, and negative values indicate dominance of the green prime. Because the value is close to zero, it appears as though neither the green nor the red prime is solely priming the target. Although there are no significant differences between the same time condition are the two, one prime control conditions, Figure 13 shows that this condition is clearly not the same as the two controls. Because the same time condition is not the same as the controls, it suggests that competitive priming is not occurring and there is some interaction between the offsets of the primes. Taken together, these results show that the offsets of the primes are most likely integrating before they prime the target.

For the difference in reaction times, the green then red condition and the red prime only condition both have slopes that are significantly different from zero and the magnitudes of the difference in reaction times between these two conditions are very similar. These two results suggest that, as seen in experiment 2, the reaction times are primed by the second (and in this case red) prime. In addition there is no significant difference between the two conditions in the mean reaction times, which further supports the conclusion that the second, red prime is priming the target.

When the green prime is in between the red prime and the red target (the red then green condition), the difference in reaction times is close to zero. In addition, there is a significant difference between the red before green and the green prime only conditions for the mean incongruent and mean congruent reaction times. This suggests that there is no priming occurring. This is an unexpected result because in experiment 2 and in the green then red condition, the second prime dominates the priming response. This shows that offset integration and priming dominance are not straightforward processes.

There are a few different explanations as to why the second prime does not dominate in this condition. It is possible that the brain ignores both primes in this case (which would also cause the difference in reaction times to be zero and for no priming effect to be seen on the mean reaction times). However, this is unlikely because both of the primes alone create a strong priming effect for these time durations. In addition, the opposite case, when the green prime is first, shows strong priming. To further test if the primes are ignored we can compare this condition to a no prime condition. If the primes are being ignored, then there will be no difference from the no prime condition. If the primes are integrating, then the mean reaction times will be slightly different from the no prime condition due to unequal integration between trials.

It is also possible that the offsets of the two primes are equally integrating and canceling each other out, but this is unlikely because this is not the case in the green then red condition or in experiment 2. In addition, the green prime is brighter than the red prime, so if integration was occurring one would expect the green prime to dominate the response because it has more energy.

Another explanation could be that because a green prime comes between the red prime and red target, that the color disruption prevents the brain from associating the primes with the target. Instead, it is possible that the brain groups the two primes together because of size and shape similarities and groups the target separately. The target could be grouped separately because the green prime comes directly before the red target, and the two primes are much more similar than the green prime and the red target. If this were the case then the primes would most likely not prime the target.

No matter what the explanation, the red before green condition shows that prime dominance and feature integration is not straightforward.

Offset of Primes

It is difficult to conclude many things from the visibility of the prime experiment because of the large standard deviation between subjects. Subjects reacted differently to the different condition. One effect that can be seen is that the subjects were always better at detecting the offset of the prime when there was no target presented. From this we see that the presence of the target does inhibit the visibility of the offsets of the primes. This could be due to partial backward masking. In addition, the average threshold of visibility of the offset of the primes across subjects was always lower than the offset presented in the priming experiment (40 arcsec). This suggests that subjects were able to perceive the offsets of the primes during the priming experiments.

4 Conclusion

We investigated how the presence of two primes will affect priming of a target. We addressed which prime dominates the priming response and if the offsets of the primes will integrate or fuse before they prime. The complexity of the results seen here shows that priming with two primes is a promising method for further investigation of priming and feature fusion, and possibly other visual phenomena, such as grouping.

When primes are presented in the same spatial location, the offsets of the primes fuse together before they prime the target. In this case, neither prime dominates the priming response, because offsets cancelled before they could prime.

When the primes are presented on separate sides of the target (and all verniers are the same color), then the offsets of the primes still integrate before priming, but in a more complex manner. When two, opposite-offset primes are presented at the same time, then, as before, the offsets fully integrate before priming occurs. This is surprising because of the relatively large distance separating the two primes. It seems as though the similarities between the two primes is enough for the brain to integrate their features. When two primes are presented with a 30 ms time delay between them, then the offsets still integrate, but the second offset dominates the priming response. This is contrary to what is expected, because the standard priming effect increases as the time between the prime and target presentation increases, and, hence, the priming effect from the first prime should be stronger, and, therefore, dominate the priming response. The unexpected dominance of the second prime can be explained by the two primes integrating before priming. If the offset information from the first prime is stored in a leaky buffer (causing the strength of the information to decrease over time), then when the two primes integrate, the information from the second prime will be stronger (Rüter et al., in revision).

My experiments have shown that there are complex mechanisms that govern which prime dominates the response and how the primes will integrate before priming. Although the offsets of the primes can fuse before they prime, changing other features of the primes (such as color or temporal location) changes how the primes interact with each other and with the target. When the primes are presented at different times, if the second prime is the same color as the target, then the second prime dominates the priming response, regardless of the color of the first prime. However, if the second prime is a different color from the target and the prime (which are the same color), then the offsets of the primes integrate before priming and neither prime dominates priming. This differential response to priming could be caused by the brain grouping the primes and targets differently when the colors change.

Although the effects are complicated, we do see that when the two offsets are not equally integrating, it is the second prime that primes the target. This result opposes many current theories of decision making and priming which predict dominance of the first vernier. In addition, we also see that when two primes are present, the offsets will interact before they prime the target. In each experiment, we saw that conditions with two primes were different from the one prime, control conditions, which suggests an integration before priming. The primes are not simply competing to prime the target, rather, they are integrating before they prime.

In the previous set of experiments, we investigated how the integration between two verniers affects how they prime the target. We see that the effects seen by priming with two primes are not straightforward; although the offsets of the primes can fuse before they prime, changing other features of the primes (such as color or temporal location) changes how the primes interact with each other and with the target.

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